Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 15 (2011) 1308 – 1312

Procedia Engineering

www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Condition Monitoring of Aircraft Sudden Failure

Zhongsheng Wang，Xiaolei Chen

School of Aeronautics, Northwestern Polytechnical University, Xi'an, 710072, China

Abstract

The sudden failures of aircraft will seriously threat its flight safety during the flight process. In order to prevent or reduce occurrence of sudden failure, a monitoring program of aircraft sudden failure by means of the conditions information and sensitive parameters is put forward and its realizing method is researched. At the some time, an example on in-flight shutdown of aero-engine is simulated. Results shown that, only if the sudden failure information of aircraft can be caught in time and the corresponding measures can be adopted, the sudden failure of aircraft can be prevented or reduced.

Selection and/or peer-review under responsibility of [CEIS 2011]

Kaywords:Aircraft; Sudden failure; Condition monitoring; In-flight shutdown of aero-engine

1. Introduction

The sudden failures of aircraft will seriously threat its flight safety during the flight process. In order to prevent or reduce occurrence of sudden failure, the extensive research on design, produce and maintenance is done and many research results are obtained [1-3]. Because the occurrence time of aircraft sudden failure is very short and it has randomness, it is very difficult in prevention. In order to increase protection ability on sudden failure, we put forward a monitoring program of aircraft sudden failure through conditions information and sensitive parameters. It is based on analysis of the sudden failure mechanism, and conduct the simulation of in-flight shutdown of the aero-engine. It provides a new thought and new method to raise the safety and reliability of aircraft as well as the protection capabilities against the sudden failure.

Project 51075330 Supported by National Natural Science Foundation of China
Tel.: 029-88491964; fax: 029-88492344.
E-mail: sazs_wang@nwpu.edu.cn.

doi:10.1016/j.proeng.2011.08.242

2. Program of Conditions Monitoring on Aircraft Sudden Failure

Aircraft sudden failure is a transient failure, always difficult to predict and prevent for its quick and random occurrence. However, it has the development process from gradual change to sudden change, therefore, the sudden failure of aircraft will be eliminated and controlled through the real-time monitoring of sensitive parameters of aircraft sudden failure during the stage of gradual change, and the proper emergency protective measures during the stage of sudden change. The condition monitoring process of aircraft sudden failure is shown in Figure 1.

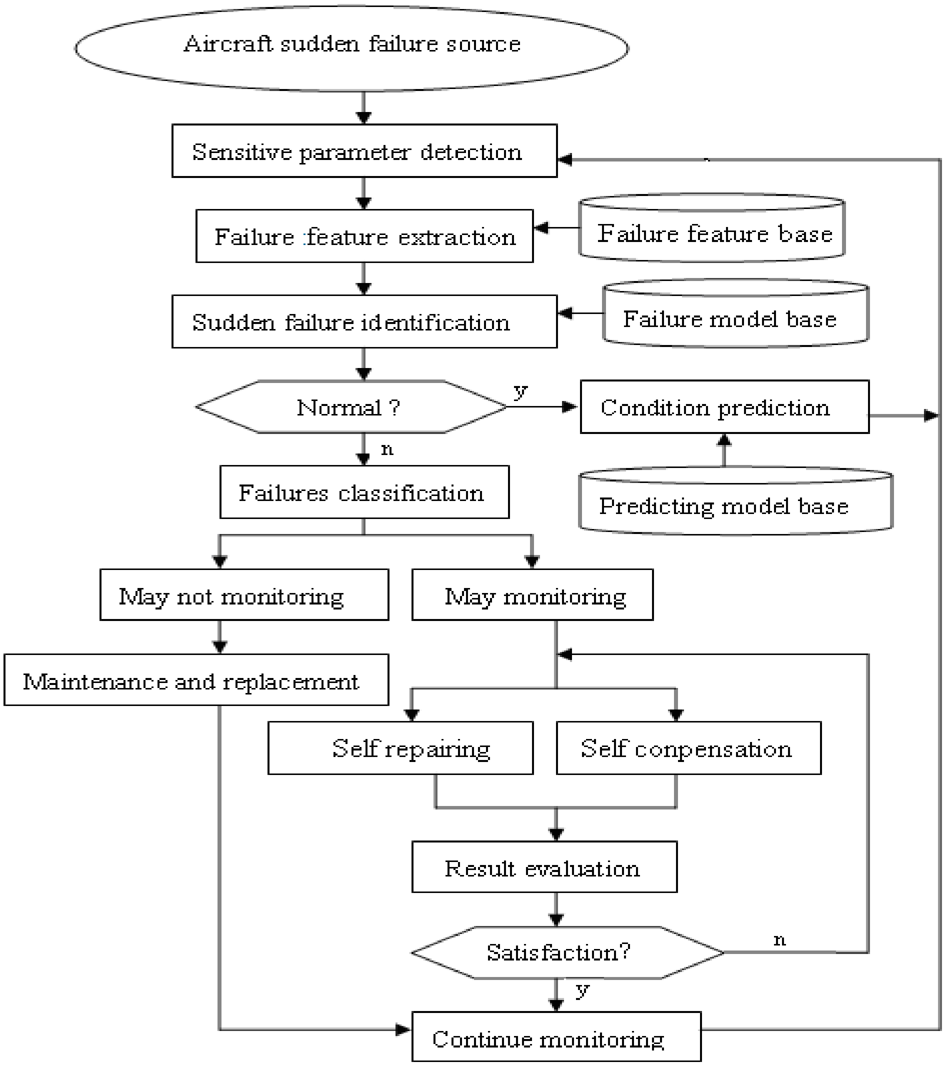

Fig.1. Conditions monitoring of aircraft sudden failure

The failure is most likely to take place in the sudden failure source of aircraft, as well as the key part and key subsystem that will pose a threat to aircraft safety, from where, the sensor can obtain the most sensitive conditions information of the sudden failure, then the sudden failure can be identified and classified after integration, optimization and feature extraction. As for the failure able to be monitored, self-compensation and self-repairing can be conducted for the sudden failure with the intellectual structure [4], smart materials [5-6], system reconfiguration [7], material and energy exchange [8-9] etc., and then through the effect evaluation, the sudden failure can be suppressed, eliminated or weakened. As to the failure that cannot be monitored, the sudden failure can be repaired through maintenance, replacement and other means.

3. Simulation Example and Result Analysis

In-flight shutdown of aero-engine is the most common form of sudden failure of the aircraft, which may occur due to many factors, such as structural damage of engine, flameout of combustion chamber, excessive oil consumption, engine overheating, engine surging, invasion of foreign objects etc.. Taking the blade damage of engine for example, the following conducts the simulation design.

During the flight of an aircraft, the engine rotor runs at high speed under high-temperature, high-pressure and high-load conditions. In case of blade damage, the air flow will be changed and the gas flow will be separated, which may lead to compressor surging and in-flight shutdown of engine if serious.

Main load of the turbine nozzle blade includes mechanical shock of the high-temperature fuel gas in the combustion chamber and thermal load due to uneven heating of the blade, among which, the thermal load accounts for a large proportion. During the engine operation, different stress force, together with different dependent variables, can be formed in different places of the blade, resulting into strain difference on the blade. In the process of repeated acceleration and deceleration of engine, the strain difference goes through several cycles and changes, leading to thermo-mechanical fatigue (TMF) of the blade. Through the stress analysis of the turbine nozzle blade during engine running, it’s calculated that total stress difference Δc_t of the blade during engine accelerating shall be:

$$\begin{aligned}\Delta c_t &= c_{\max} - c_{\min} \\ &= (\sigma_{1,\max} + \sigma_{2,\max}) - (\sigma_{1,\min} + \sigma_{2,\min}) \\ &= f(\Delta T_{\max}, T_{metal(\Delta T_{\max})}) + f(p_i)\end{aligned} \qquad (1)$$

Where, $\Delta T_{\max}$ Maximum temperature difference between the turbine front and rear during the process of acceleration

$T_{metal(\Delta T_{\max})}$ Blade temperature corresponding to the temperature difference $\Delta T_{\max}$

p_i Pressure of the front and rear of turbine during engine running

The total strain difference of blade $\Delta\varepsilon_t$ shall be:

$$\frac{\Delta\varepsilon_t}{2} = \frac{\Delta\sigma_t}{2E} + \left(\frac{\Delta\sigma_t}{2K}\right)^{\frac{1}{n'}} \qquad (2)$$

Where, K Cyclic strength coefficient

n' Cyclic strain hardening index

E Elasticity modulus of materials

Substitute equation (2) into formula Manson-Coffin, and then the Mises equivalent strain amplitude can be got

$$\frac{\Delta\varepsilon_t}{2} = \frac{\sigma_f^{'}}{E}(2N_f)^b + \varepsilon_f^{'}(2N_f)^c \qquad (3)$$

Where, $\sigma_f^{'}$ Fatigue strength coefficient

b Fatigue strength index

$\varepsilon_f^{'}$ Fatigue plasticity coefficient

c Fatigue plasticity index

N_f Fatigue lifetime of blade

According to the 10% principle (that is, with considering of the role of creep damage, the fatigue lifetime $N_f^{'}$ will be shortened to 10% of original fatigue lifetime N_f), the fatigue lifetime $N_f^{'}$ of blade under high temperature shall be

$$N_f^{'} = f(\Delta T_{\max}, T_{melal(\Delta T_{\max})}, p_i) \qquad (4)$$

Remaining lifetime N_l for the fatigue and damaged of blade shall be

$$N_l = \frac{D}{1/N_{fn}} = N_{fn}\left(\sum_{i=1}^{n}\frac{1}{N_{fi}}\right) \qquad (5)$$

Where, n Fatigue damage cycles

N_{fi} Fatigue damage cycles obtained in the No. i calculation

N_{fn} Fatigue damage cycles obtained in the No. n calculation

Figure 2 shows the simulation model of monitoring system on blade damage.

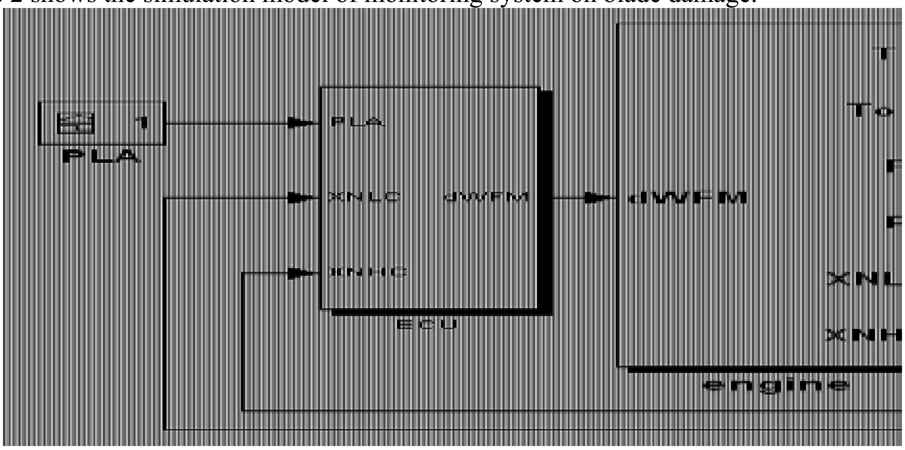

Fig.2. Simulation model of monitoring system on blade damage

In the figure, engine module is the model of certain packaged turbofan engine, for which, the input is the fuel amount dWFM, and the output includes the front and rear temperature of turbine Tin and Tout, pressure P3 and P6, the rotor speed under high and low pressure XNLC and XNHC; while, ECU module is the controller of engine of this type.

The pilot gives the acceleration command through the throttle lever PLA, and the controller calculates the required fuel flow currently and inputs to the engine module, while the blade lifetime module can calculate the damage suffered during the flight based on real-time collecting data, and gives the remaining lifetime of blade. For the simulation result, see Table 1.

Tab.1. Simulation Results of Blade Damage

PLA	$Rise\ Time / s$	T_{41} / K	$\Delta T_{\max} / K$	$\Delta\varepsilon_t$	$N_f^{'}$
40-70	1.35	1756.41	545.52	0.015253	4662
50-70	0.93	1746.25	541.06	0.015048	5077

It can be seen from Table 1 that, the blade damage varies under different accelerations, and the sharper accelerate, the more damage of the blade becomes. Once the damage accumulates to a certain extent, the blade will be damaged seriously or even broken, leading to in-flight shutdown of engine. In order to prevent the shutdown due to blade damage and other sudden accidents, real-time monitoring of the blade damage value shall be conducted to limit it within the damage threshold, or the number and speed of acceleration and deceleration shall be controlled.

4. Conclusions

Sudden failure of aircraft is a transient failure, and also the evolutionary process from the gradual and slight change to the sudden and emergent change. As long as the sensitive parameters and conditions information are captured timely during the evolution process of sudden failure, and appropriate measures are taken, the sudden failure of aircraft can be prevented or reduced.

References

[1] Silveira E, Atxaga Irisarri AM. Failure analysis of two sets of aircraft blades. *Engineering Failure Analysis*, 2010, 17（3）：641-647

[2] Etemadi AR, Behjati P, Madaah HR, Kokabi AH. Failure analysis of brazed air passages of an aircraft fuel system. *Engineering Failure Analysis*, 2010, 17（6）:1495-1499

[3] Ukil A, Živanović R. The detection of abrupt changes using recursive identification for power system fault analysis. *Electric Power Systems Research*, 2007, 77(3-4): 259-265

[4] Decker SL. Tactile measures in the structure of intelligence. *Canadian Journal of Experimental Psychology,* 2010, 64(1): 53-59

[5] Song G, Sethi V, Li HN. Vibration control of civil structures using piezoceramic smart materials: A review. *Engineering Structures*, 2006, 28(11): 1513-1524

[6] Ng CO, Rudraiah N, Nagaraj C. Electrohydrodynamic pulsatile flow in a channel bounded by porous layer of smart material. *International Journal of Engineering Science,* 2009, 47(1): 103-115

[7] Mata JL, Rodríguez M. Accident prevention by control sestem reconfiguration. *Computers & Chemical Engineering*, 2010, 34(5): 846-855

[8] Lurie KA, Weekes SL. Wave propagation and energe exchange in a spatio-temporal material composite with rectangular microstructure. *Journal of Mathematical Analysis and Applications*, 2006, 314(1): 286-310

[9] Tsakirtzis S, Vakakis AF, Panagopoulos P. Broadband energe exchanges between a dissipative elastic rod and a multi-degree-of-freedom dissipative essentially non-linear attachment. *International Journal of Non-Linear Mechanics*, 2007, 42(1): 36-57